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O. MATSUDA AND H. YAMADA

INVESTIGATION OF THE MANUFACTURE OF
BUILDING MATERIALS BY CARBONATION HARDENING
OF SLAKED LIME

SEKKO TO SEKKAI, (125): 170 - 179, 1973

TRANSLATED BY / TRADUCTION DE

THOMAS WILDS

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PREPARED FOR THE DIVISION OF BUILDING RESEARCH

TRADUCTION NUMÉRO 219 DE LA SÉRIE PRÉPARÉE POUR
LA DIVISION DES RECHERCHES EN BÂTIMENT

OTTAWA

1975



PREFACE

There is renewed interest in concrete technology in recent years about the possibility of manufacturing carbonated concrete products. Some work has also shown that it is possible to produce carbonated lime products of good strength. There is a good possibility that in future more effort will be directed to find ways of using effluent gases such as carbon dioxide to produce new products.

This paper describes comprehensive work carried out by three laboratories in Japan to determine the conditions necessary to produce a durable building material using carbon dioxide issuing from lime-burning kilns. Parameters studied are mix proportions, compaction pressure, temperature, humidity, and addition of different materials.

Ottawa

June, 1975

C.B. Crawford

Director

Division of Building
Research

NATIONAL RESEARCH COUNCIL OF CANADA
CONSEIL NATIONAL DE RECHERCHES DU CANADA

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INVESTIGATION OF THE MANUFACTURE OF BUILDING MATERIALS
BY CARBONATION HARDENING OF SLAKED LIME

This paper describes the results of joint study by the authors and the researchers of Industrial Research Institute of Kōchi, Ōita and (Fukushima) Fukuoka prefecture.

In order to try to manufacture a building material by means of carbonation of slaked lime, the influences of experimental factors on principle properties of the material were investigated.

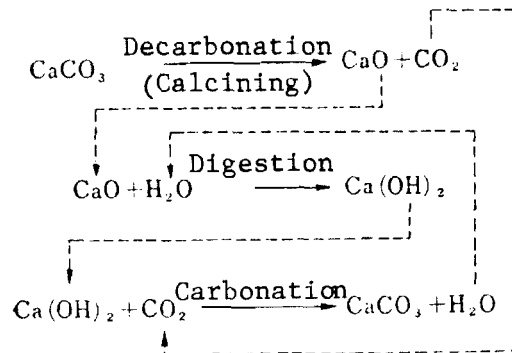
From this study, effects of mix proportion, moulding pressure and conditions of carbonation could be clarified and a possibility to make the building material was suggested.

This report brings together a summary of the results of joint investigations of three laboratories in Kōchi, Ōita and Fukuoka (Fukushima) Prefectures, concerning the manufacture of building materials based on hardening slaked lime by forced carbonation.

1. Introduction

In the past, slaked lime has been used as a material for plastering walls. Hardening occurred by natural drying and absorption of CO_2 gas in the air. But building materials now tend to be prefabricated in plants, and there is thought to be little hope for extending the wet production method to on-site plastering.

What sorts of materials can be manufactured by forced carbonation of slaked lime? Is it not possible to make practical use of the waste gas in lime-calcining furnaces as a CO_2 gas source? If coal enterprises were to do this they would have a closed system as far as the materials are concerned, as shown below.



That is, if the waste gas can be used and aggregates can be blended, its utility can be considered in terms of its material properties. These are some of the conceptual starting points.

This report is a summary of the results of experimental investigations aimed primarily at investigating the effects of manufacturing factors on building material properties, in order to obtain a perspective on the manufacture of building materials with calcite binder made by forced carbonation of slaked lime.

2. Carbonation and Hardening of Slaked Lime

The authors have made prior investigations⁽¹⁾ regarding carbonation of slaked lime, and have indicated that there is an optimum amount of moisture to be added to the slaked lime to raise its carbonation speed, the initial reaction is rapid and the carbonation proceeds faster the higher the wetness of the atmosphere, and the main mineral formed is calcite. They also believe that the slaked lime carbonation reaction is a solution reaction when there is much liquid water, but that a topological reaction occurs when there is little moisture.

Figure 1 shows the depth to which the specimen is carbonated as shown by colorimetry using phenolphthalein, the specimens being 30:70 blends of Sango coal (0.15 mm maximum size) in slaked lime with 10% water and they were formed under pressure in an axial direction.

It was found that the higher the forming pressure, the slower the permeation of the gas.

Figure 2 shows the carbonation amount (by the weight method) of hardened pressure-formed bodies of size $20\phi \times 20$ mm after being exposed for one day in a 0.5 litre/min CO_2 gas atmosphere at 20°C , and also shows the relation between the forming pressure and the bulk density and compression strength.

Removal of free moisture from carbonation was attempted using CaCl_2 . When the forming pressure is raised, the bulk density and compressive strength increase up to a point (Figure 2) because carbonation is affected by the rise in forming pressure (that is, a decrease in the formation of the calcite that serves as a binder), and in a formed body with a low percentage of voids, the slaked lime swells by about 12% from carbonation.

Figure 3 shows the strength of the hardened bodies of dimension $4 \times 4 \times 16$ cm of silasparite⁽²⁾ blended with slaked lime and pressure formed at 10 kg/cm^2 to make lightweight building material, and carbonated for eight hours at 40°C .

The bulk density can be controlled to a certain degree by the mix proportions and the forming pressure.

3. Slaked Lime and Dolomite System (Press Forming)

Kochi Prefecture Industrial Technology Laboratory, Messrs. Takeo Sakae, Kiekata Imai, Masamichi Fujiwara and Hisaichi Sekida.

The experiments were done by mulling a powder base material such as slaked lime and a fine aggregate such as dolomite with prescribed amounts of water,

compressed in metal molds ($2 \times 2 \times 8$ cm) to a height of 16 ± 0.5 mm. Then the pressure-formed samples were inserted into a tank ($\phi 45 \times 45$ cm) at constant temperature and constant pressure, and carbonation was carried out at a prescribed concentration of carbon dioxide gas introduced at a flow speed of 300 ml/min. For regulating the moisture inside the tank, calcium chloride or water was placed at the bottom, and the humidity was adjusted. The amount of carbonation was determined by thermogravimetric analysis.

3.1 Effects of type of base material

Three series of experiments were carried out. A 60:40:9 mixture of base material, aggregate and added water was made at a pressure of 200 kg/cm^2 , and the carbonation conditions were low moisture, 20°C , and a gas concentration of 100%. The results showed carbonation amounts in the range of 31 - 96%, bending strengths of $39 - 159 \text{ kg/cm}^2$, and compressive strengths of $115 - 848 \text{ kg/cm}^2$. The amount of carbonation, bending strength and compressive strength of the base materials increased in the order $\text{Si} + \text{HD} > \text{Si} + \text{DP} > \text{Si} > \text{Sa}$, but this effect was about 10% for the carbonation amount and within about 30 kg/cm^2 of the bending strength (Table 1). With the aggregate only the bending strength was meaningful, the dolomite being of somewhat higher strength. Subsequent experiments were made with mixtures of slaked lime (elemental lime) and dolomite aggregate.

3.2 Effects of the aggregate and the forming pressure conditions

The factors and levels of the experiment were allotted in an orthogonal arrangement $L_{27}(3^{13})$, and the carbonation conditions were low moisture, 30°C and 24 hours. The characteristic values obtained were 27 - 94% carbonation rate, $46 - 123 \text{ kg/cm}^2$ bending strength, $233 - 797 \text{ kg/cm}^2$ compression strength, 1.61 - 2.24 bulk specific gravity, and $< 0.25 \%$ shrinkage rate. As the particle size of the aggregate varies from fine to medium to coarse the bending strength

increases, while the amount of aggregate and the forming pressure are quantitative factors and thus their levels were arranged at equal intervals, When we assumed the strength and the amount of aggregate at which the strength is maximum, we obtained a response curve from an orthogonal polynomial for the strength, and performing differential calculus for the amount of aggregate, we got, for the bending strength, an amount of aggregate of 56.6% and a maximum strength of 103 kg/cm² with the forming pressure of 250 kg/cm², these being respectively 58% and 119 kg/cm² with the 400 kg/cm² forming pressure, and for the case of compressive strength we got respectively 57.3% and 743 kg/cm² at a forming pressure of 250 kg/cm² and 71.8% and 682 kg/cm² at the 400 kg/cm² forming pressure. From these facts it is believed that the phenomenon of strengthening of the carbonated hardened bodies is a composite action of the forming pressure on the packing density of the formed body and the binding force of the calcium carbonate formed and the aggregate. From these results it was concluded that a forming pressure of 250 kg/cm² and an amount of aggregate (fine grained) of 55% would be suitable for both types of strengthening in subsequent tests.

3.3 Effect of the carbonation reaction conditions

The factors and levels of the experiment were arranged in three sets, and the characteristic values obtained were carbonation rates of 19 - 91%, bending strength 83 - 183 kg/cm², compressive strength 173 - 1,055 kg/cm², and moisture absorption 8 - 12.5%. The carbonation advanced at a higher level at 20°C and 50°C, but at 80°C when the gas concentration was 30%, the carbonation declined markedly, and even with a gas concentration of 100% it was in the same order as at 50°C. The moisture absorption rate declined with the progress of carbonation. The compressive strength showed different behaviour depending on the reaction temperature, the maximum strength being shown at 50°C. This trend was also found in the bending strength, but to a lesser degree. According to scanning electron microscope photographs of the materials carbonated at different reaction temperatures, the development of calcite crystals was

insufficient at 20°C, there were calcite state crystals of a few microns at 50°C, and they developed to about 10 microns at 80°C. This is inferred to play a role in the dependence of temperature on the strength.

3.4 Effect of variations in the carbonation method

The factors and levels were arranged orthogonally as $L_{16}(2^{15})$. The characteristic values obtained were 32 - 71% carbonation, 41 - 121 kg/cm² bending strength, and 165 - 287 kg/cm² compressive strength. These characteristics depend strongly on how the reaction was carried out, reaction temperature, the early humidity, the moisture added and their combined actions. This is believed to be so because the effect of moisture in the reaction system is related to the progress of the carbonation reaction, so that one factor alone does not account for all the effects.

3.5 Effect of addition of mixing materials

We investigated the effect of additions of high molecular materials and fibres, and it was possible to raise the wear resistance with 2% additions of PVA and SBR, and to raise the impact strength by 5 - 10% additions of asbestos.

3.6 Optimum factors for manufacturing and comparison with building materials on the market

Table 5 shows the factors that give carbonated hardened bodies high strength. Upon comparing building materials manufactured under these conditions with the characteristic values of commercial building materials measured under nearly the same conditions, the manufactured trial materials displayed sufficient strength, and also were easily brought to a lustre by surface polishing and could be given clear colors.

4. Slaked Lime-Waste Powder Systems (Press Forming)

Oita Prefecture Industrial Technology Laboratory, Messrs. Shikami Sato, Hiroshi Miki, Wataru Doi, Akimoto Todaka and Yoshie Kiyomizu.

4.1 The assignment was to make carbonated hardened bodies with mixtures of slaked lime and waste powders. The waste powders employed were limestone powder and nickel slag (electric furnace method). The particle size of the powders was less than 250 μ .

The experiments were done by mixing slaked lime and the powder, adding considerable water and press forming, after which they were forcefully carbonated and hardened in a stream of carbon dioxide gas. Investigations were made of the relation between strength and conditions such as blending, forming and the reaction.

4.2 Preparing the materials

The powders were crushed in a pulverizer and screened in standard screens of 250 μ , 149 μ and 74 μ to the sizes shown in Table 2 [sic - 8 intended].

The powders thus prepared were blended with 30%, 50% and 70% slaked lime, and 4 - 12% water was added.

4.3 Reaction conditions

The materials were pressed at 100 - 700 kg/cm² in metal molds (2 × 2 × 12 cm), and then placed in a reaction vessel through which carbon dioxide gas was passed.

The reaction temperatures were from ambient to 80°C, and the interior of the vessel was at normal pressure and in a wet condition. The carbon dioxide gas concentrations were 100% and 30%.

4.4 Grain size grading and moisture addition

In regard to grain size grading, medium grain sizes (close to maximum packing) gave high strength, but blends close to a single grain size were not good.

The addition of water has no relation to the ease or difficulty of forming, and when we disregard formability, the suitable amount of moisture required for carbonation hardening is about 6% with medium grain size, and about 8% with fine grains. Since the water added adheres to the grains in the formed body or enters the interstices between the grains, it is raised or lowered depending on the size of the powder grains (difference in specific surface area) and the forming pressure. Products with little added water gave better carbonation.

4.5 Slaked lime mixing

The slaked lime mixing is related to the amount of reactive calcium carbonate. The slaked lime increases in volume (about 12%) by carbonation, the spaces inside the formed body are filled, and the grains are tightly compressed together.

When the slaked lime is 100% its swelling proceeds in the same way, but cracking occurs in the formed body and strength declines, but products of high strength can be obtained by using a suitable mixing of slaked lime. As shown in Figure 7, with reaction temperatures from room temperature to 40°C a suitable mixing is obtained with 70% slaked lime, while at 60 - 80°C it is about 50%.

4.6 Forming pressure

The density of the formed body increases as the forming pressure becomes higher. Since it is difficult for carbonation to occur unless there are interstices in the formed body, the carbonation rate will decline if the forming pressure is too high. A forming pressure of 400 kg/cm² is suitable. An example is given in Figure 8.

4.7 Reaction temperature and reaction time

Extending the reaction time during the carbonation reaction raises the strength and carbonation rate. In bodies made under high forming pressure the carbon dioxide gas and the reaction-feeding water pass through with difficulty, and when the reaction time is too short the carbonation occurs only on parts near the surface, and it is difficult to obtain strength. When the reaction time is lengthened, penetration proceeds into the interior resulting in higher strengths.

The carbonation reaction of the slaked lime produces carbon dioxide gas and an equivalent amount of water, and since it is an exothermic reaction, the water is converted to steam and leaves the specimen to fill the reaction vessel and makes it wet. The compact is therefore continuously carbonated without water drops adhering to its surface. At reaction temperatures under 40°C the reaction vessel is in a wet state due to the water produced by the reaction. At temperatures over 60°C the specimen dries and there is insufficient moisture for carbonation, and it will be necessary to add water.

With a high temperature and 100% carbon dioxide gas, the carbonation will advance rapidly in the initial reaction stage and will generally be completed after 6 - 12 hours resulting in a product of high strength.

With a high temperature and 30% carbon dioxide gas, the carbonation advances slowly, and hence it is necessary to perform the reaction for more than 24 hours to achieve high strength (see Figure 9).

4.8 The carbonation amount and strength

Generally the strength increases with the progress of carbonation, but when the reaction takes place at too high a temperature there is a tendency for products made by high forming pressures to decline in strength. This is perhaps due to the strains occurring inside the hardened body resulting from the growth of calcium carbonate grains and the swelling that results from carbonation.

When hardened bodies were cut and stained with phenolphthalein, carbonation was found to progress from three layers to a single layer, as shown in Table 9. We also investigated the progress of the carbonation by determining the amount of carbonation by thermobalance.

4.9. Conclusion

The carbonated hardened bodies with slaked lime as the basic material and limestone powder system, had compression strengths of 700 - 1,000 kg/cm², bending strengths of 70 - 100 kg/cm², bulk specific gravity of about 2, and moisture absorption of about 11%; the nickel slag system had compressive strengths of 800 - 1,100 kg/cm², bending strengths of 70 - 150 kg/cm², bulk specific gravity of about 2.1, and moisture absorption of about 11%, and it was possible to make products with strengths higher than are obtainable for concrete products.

5. Lime-Limestone System (Papermaking)

Fukuoka Prefecture, Fukushima Industrial Technology Laboratory, Messrs. Mizutoshī Koga, Tashirō Ōtsubo, Hideichī Kamei and Yasusane Okuda.

5.1 Introduction

Asbestos cement sheet and pulp cement sheet have been made in the past by wet building material manufacturing methods using cement as the base material. These investigations concerned a wet sheet building material manufacturing method (papermaking method) with lime as the base material.

5.2 Experiments

(1) Samples

Slaked lime: Nippon Sekkai (Nippon Lime) (specially selected slaked lime).
Quicklime: Furutegawa Sangyō (Furutegawa Industries). Limestone: Nichibe Kagaku (Nishibe Chemicals) (for road building). Asbestos: Johns Manville (6D-30).
Pulp: Kogami, bleached kraft.

(2) Figure 10 shows the course of the experiments.

The experimental method was to beat pulp immersed in water in a beater, then adding asbestos and beating for a short time and dehydrating on an 80 mesh metal screen. The fibre was fed into a mixing tank and slaked lime and limestone powder were added and agitated. It was uniformly mixed to a concentration of about 4%, 1 ppm of a polyacrylamide type cohesion agent was then added, and this resulted in a weak flux. Then water was added to the mixing tank at a concentration of about 1%, it was placed in the wet machine, the material scooped up on a cylinder was moved to felt (?), dehydration was done by suction and it was wound on a making (?) roll. When it was of a prescribed thickness, it was cut and made as a raw sheet. This raw sheet was cut, pressed under prescribed pressures, dried at 105°C for more than 4 hours, and the water content was controlled. Then the samples were placed in a vacuum drier, carbon dioxide gas was introduced at close to a vacuum, and the pressure was brought back to nearly normal. When the carbonation reaction began, the gas pressure declined, and carbon dioxide gas was again introduced. When this operation was repeated and the pressure did not decline even after standing for a long period of time, the samples were removed. Some of the samples were given continuous drying and carbonation at a pulp cement sheet plant (CO₂ concentration 1.9% under heavy oil combustion, furnace interior temperature 160°C, treatment time 31 minutes). The samples were then subjected to the following physical tests.

(1) Bulk specific gravity, moisture absorption rate, bending strength:
(JIS A 5415 based on pulp cement sheet).

(2) Combustibility test: JIS A 1321

(3) Differential scanning calorimetric analysis-thermobalance: Rigaku Denki (Rigaku Electric) DSC-TG.

5.3 Test results

- (1) Mixing proportions and papermaking conditions (Table 10).
- (2) Results of physical tests (Table 11).
- (3) Results of tests on effect of pressing (Table 12).
- (4) Results of tests on optimum blend proportions (Table 13).
- (5) DSC-TG curves (Figure 11).

5.4 Discussion

(1) Table 11 and Table 13 show papermaking is possible with a wet machine with products containing 50% or more of slaked lime and using asbestos and pulp. When the amount of asbestos was over 20%, the slaked lime and asbestos became sticky, the dehydration rate declined, the cylinder was fouled, blanket stains appeared and papermaking was difficult. Since the raw sheet was soft it was difficult to handle, but this was overcome with limestone blending. The cement addition was beneficial for strength, but mars the whiteness of the lime and is not desirable.

(2) Effect of connecting pressure

As seen from Table 12, the pressure did not have much influence up to 30 kg/cm², but at 40 kg/cm² the bending strength increased greatly. This effect was especially marked as the added amount of asbestos increased.

(3) Product characteristics

Table 12 and Table 13 show that the moisture content was very low and was 1 - 4% for all samples, and water absorption stabilized within a narrow range around 40%, showing high values as a building material containing fibres. The bending strength depends greatly on the amount of asbestos, but the values obtained are higher than those for prior interior finishing for air drying time. However, as is seen in Table 13, the strength decreased with water absorption. This is thought to have a significant relation with the amount of remaining slaked lime (carbonation rate). Figure 11 shows the amount of unreacted slaked lime in samples after completion of carbonation, and it may well be that slaking occurs in the water and there is a decline in strength due to it.

(4) Combustibility

The products satisfy all of the conditions for Td•0, C/A, residual flame, deformation and cracking prescribed in the JIS and are thought to have sufficient incombustibility, and can be classified among the first class of incombustibles.

(5) Concerning the carbonation

In the DSC curves in Figure 11, there are rather broad exothermic peaks between 320 and 350°C whether the samples are carbonated or not, suggesting the combustion of pulp fibre, and the TG curves also show similar curves indicating weight changes. The small exothermic peaks in the vicinity of 420°C and the slight weight increase were not anticipated, and there seems to be a need for further investigation that would consider the reaction between the unreacted slaked lime and the carbon dioxide gas formed. The endothermic peaks at 470 - 550°C show the presence of slaked lime, but even in the carbonated samples faint peaks appear, indicating that complete carbonation does not occur.

5.5 Conclusion

It is possible to use slaked lime in papermaking and to make fibre blends in wet machines, and the carbonated and hardened bodies thus produced satisfy the requirements for interior finishing building materials. However there are many problems connected with increasing the strength, with its resistance to water and promoting the carbonation reaction. Investigations are now in progress to establish a continuous dry carbonation process utilizing waste gas for commercialization.

6. Summary

There are still problems connected with durability and water resistance of building materials made by the carbonation of slaked lime, but these problems

are both being investigated, and they should be settled soon. It is not anticipated that either of them will be problems from the standpoint of actual use.

We will be satisfied if this report can give some clues to the development of a new field of utilization for lime, to the use of blendable unused natural resources, and the development of new building materials, as well as make a contribution to the advance of related fields of investigation.

In conclusion, it should be noted that these investigations were made as part of a fiscal year 1971 Technical Development Research Fund Supplemental Project of the Smaller Enterprises Agency.

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Table 1 Factors and Levels of Experiment (1)

Factors	Levels			
	1	2	3	4
Bonding material	Si	Sa	Si · DP	Si · HD
Aggregate	Lime Stone	Dolomite		
Carbonation time	3 hr	9 hr	27 hr	54 hr

Si; Slaked lime (simple)

Sa; Slaked lime (salt)

Si · DP; Si: Dolomite plaster=1:1

Si · HD; Si: Half burned dolomite (730°C)=1:1

Table 2 Factors and Levels of Experiment (2)

Factors	Levels			
	1	2	3	
Mix proportion of aggregate (%)	35	50	65	
Particle size of aggregate	coarse	medium	fine	
Pressure of moulding (kg/cm ²)	100	250	400	
Particle size distribution of aggregate				
mm	2.5~1.2	1.2~0.6	0.6~0.3	0.3~0.15 <0.15
Coarse	35	35	15	15
Medium	15	35	35	15
Fine		15	35	35

Table 3 Factors and Levels of Experiment (3)

Factors	Levels		
	1	2	3
Carbonation temp.	20°C	50°C	80°C
Concentration of CO ₂	30%	100%	
Carbonation time	8 hr	16 hr	24 hr

Table 4 Factors and Levels of Experiment (4)

Factors	Levels	
	1	2
Carbonation temp	30°C	70°C
Carbonation type	continuous	closed
The former humidity	low	high
The latter humidity	low	high
Moisture content	20%	25%

Continuous: carbonated under CO₂ gas flow

Closed: carbonated under 0.5 kg/cm² pressure of CO₂

The former humidity: humidity during the former 4 hrs

The latter humidity: humidity during the latter 4 hrs

Table 5 Optimum Condition of Manufacturing

Factors	Levels
Material	slaked lime-dolomite
Aggregate	fine particle 55~60%
Moulding pressure	250 kg/cm ²
Moisture content	20%/slaked lime
Carbonation temp.	50°C
Humidity	low during the former term
Carbonation type	closed (or continuous)

Table 6 The Properties of Carbonated Specimen Compared with Some Building Material on the Market

Properties Specimens	Bulk density (g/ml)	Water absorption (%)	Bending strength (kg/cm ²)	Compressive strength (kg/cm ²)	Abrasion index (mg/ 1000 cycles)	Impact strength (kg/cm)
Carbonate bond specimen	2.2	3.5	160	820	(3800)* 5200	(60)** 27
Marble (natural)	2.7	0	70	620	11200	55
Cement mortar W/C=50%, 28days	2.1	9.2	120	510	7000	15

* mixed with poly-vinylacetate emulsion 2%/slaked lime and aggregate mix

** mixed with asbestos fibre 10%/slaked lime and aggregate mix

Table 7 Raw Materials for Experiment

Material		Reference
Bond	slaked lime	industrial high class
Aggregate	powder of lime stone	produced at Tsukumi city, Oita prefecture
	Ni-slag	Ferro-nickel slag SiO ₂ 51%, R ₂ O ₃ 6%, MgO 37%
Water	City service water	
CO ₂ gas	industrial	

Table 8 Particle Size Distribution of Aggregate

Particle size (μ) Aggregate	250~149	149~74	74~0
Coarser	80	10	10
Medium	40	20	40
finer	10	10	80

Table 9 The Rate of Carbonation and the Strength of Carbonated Specimen




Carbonation time (hr)	6	12	24
Carbonation temp. (°C)	80	80	80
Coloured section by phenol-phthalein			
The rate of carbonation of inner section (%)	44	61	85
The rate of carbonation of outer section (%)	85	82	85
The rate of carbonation of all section (%)	49	64	80
Compressive strength (kg/cm ²)	728	1,031	978
Bending strength (kg/cm ²)	156	165	140

Table 10 Mix Proportions of Raw Materials and their Screening States

No.		1	2	3	4	5	6	7	8
Mix proportion	Materials								
	Slaked lime	80	60	60	60	0	70	50	60
	Quick lime	0	0	0	0	60	0	0	0
	Lime stone	0	10	10	0	10	0	10	0
	Asbestos	20	20	10	10	10	20	10	40
	Pulp	3%/ mineral	10	10	10	10 (waste paper)	10 (waste paper)	10 (waste paper)	3%/ asbestos
	Serpentine	0	0	0	10	0	0	10	0
	Cement	0	0	10	10	10	0	10	0
	Summary	no good	good	good	very good	good	no good	very good	no good

Table 11 Properties of Fibre Reinforced Carbonate Plate

Carbonation	No.		1	2	3	4	5	6	7	8
	Test									
In waste gas CO ₂ 1.9%	Bulk density		1.2	1.2	1.0	1.0	1.2	1.1	1.2	—
	Bending strength (kg/cm ²)	length wise	80.2	80.4	40.8	35.4	58.6	56.7	43.6	—
		cross ways	39.6	44.4	18.6	22.8	30.0	8.2	26.0	—
In vacuum desicator CO ₂ 100%	Bulk density		1.4	1.2	1.1	1.0	1.1	1.1	1.2	1.4
	Bending strength (kg/cm ²)	length wise	176.8	80.6	30.3	49.2	54.0	62.9	161.6	71.6
		cross ways	85.5	42.4	18.3	20.9	30.6	31.4	82.1	44.6
	Difficult combustible properties	Td-θ	0	0	0	0	0	0	0	0
		C/A	0	6	4	4	11	4	14	0
		residual flame	—	—	—	—	—	—	—	—
		deforming and cracking	—	—	—	—	—	—	—	—

Table 12 Press Effect on Green Plate

Mix proportion wt (%)	Pressure (kg/cm ²)	Bending strength length wise (kg/cm ²)	Thickness (mm)	Bulk density	Moisture content (%)	Water absorption (%)
Slaked lime 60	20	68.6	5.2	1.19	1.36	38.6
Asbestos 40	30	83.3	5.1	1.30	1.56	34.6
Pulp 3/asbestos	40	153.0	6.5	1.19	1.22	39.1
Slaked lime 80	20	83.4	5.2	1.03	2.52	50.3
Asbestos 10	30	85.1	5.2	1.06	2.68	51.5
Pulp 10	40	88.5	5.3	1.04	2.31	48.7
Slaked lime 45	20	30.3	5.1	1.12	2.62	44.3
Lime stone 45	30	27.3	4.6	1.13	2.46	43.8
Asbestos 3	40	42.0	6.6	1.20	1.88	39.0
Pulp 7						

Table 13 Test Results under the Optimum Mix Proportion of Plate

Mix proportion (wt %)	Raw materials		Slaked lime	Lime stone	Asbestos	Serpentine	Cement	Pulp
	No.							
	a		60	20	10	0	0	10
	b		70	10	10	0	0	10
	c		60	0	10	10	10	10

Test results	No.	Thickness (mm)	Moisture content (%)	Water absorption (%)	Bulk density		Bending strength (kg/cm ²)			
					air dry	absolute dry	air dry (1)		water saturate (2)	
							length wise		cross ways	
							length wise	cross ways	length wise	cross ways
a		5.72	4.1	41.2	1.2	1.1	37.2	35.8	27.0	16.1
b		5.33	3.8	41.6	1.2	1.2	43.9	28.0	26.1	15.0
c		7.52	3.6	41.2	1.2	1.1	44.9	28.2	30.6	12.0

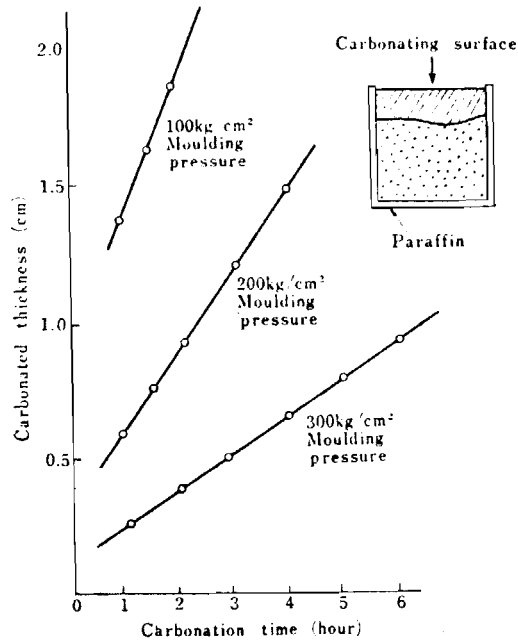


Fig. 1 Carbonated thickness of specimen

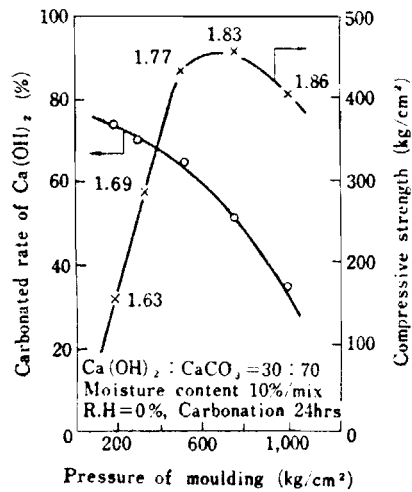


Fig. 2 Correlation of the rate of carbonation, the compressive strength and the pressure of moulding (figures in Fig. are bulk density in absolute dry state)

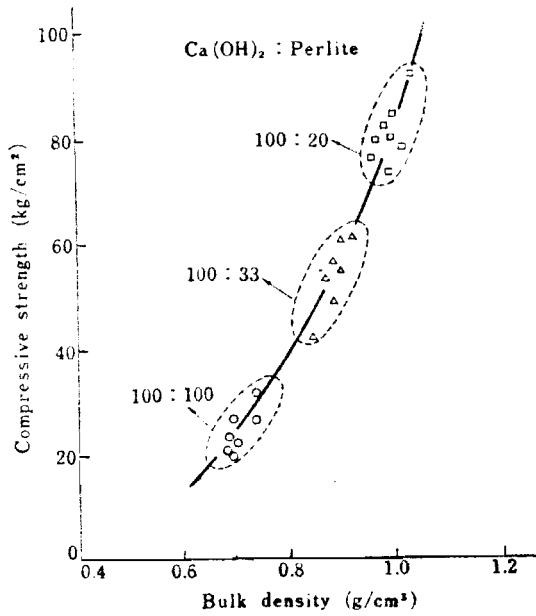


Fig. 3 Compressive strength of light weight carbonate concrete

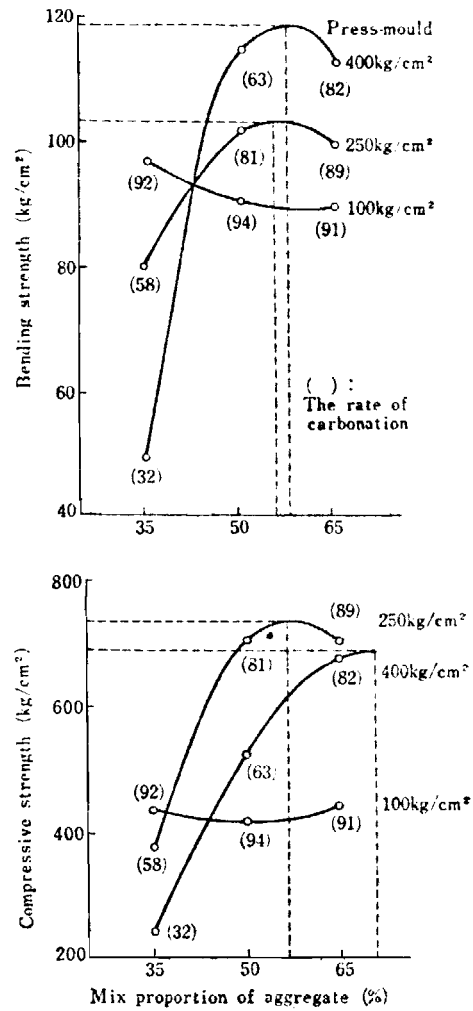


Fig. 4 Relation between the strength and the mix proportion

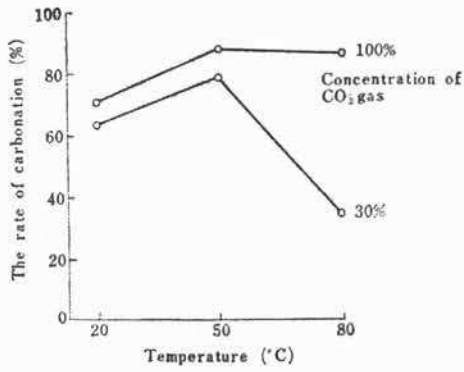


Fig. 5 Relation between the rate of carbonation and the temperature

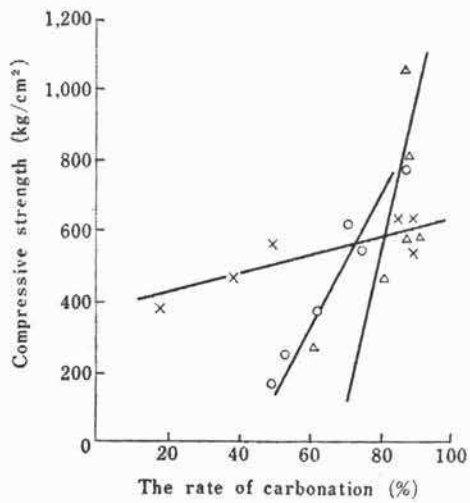
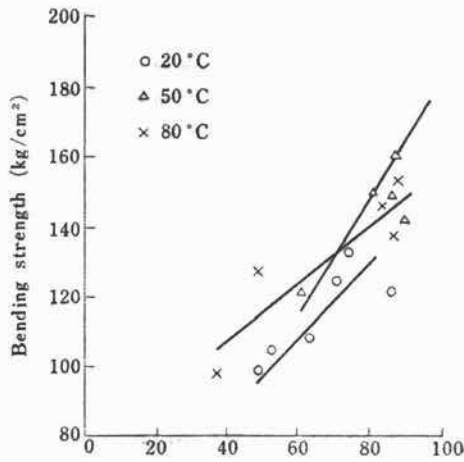
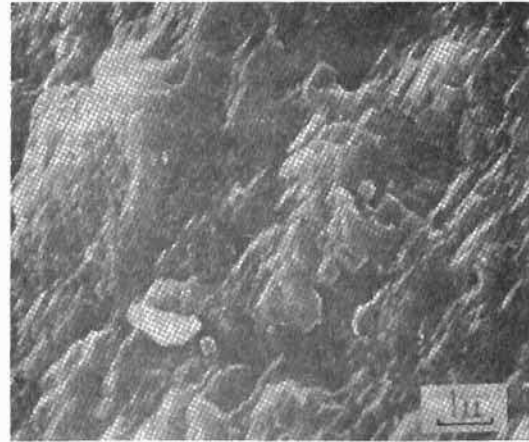
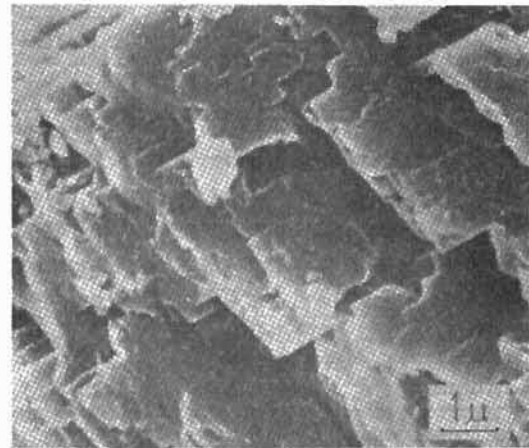


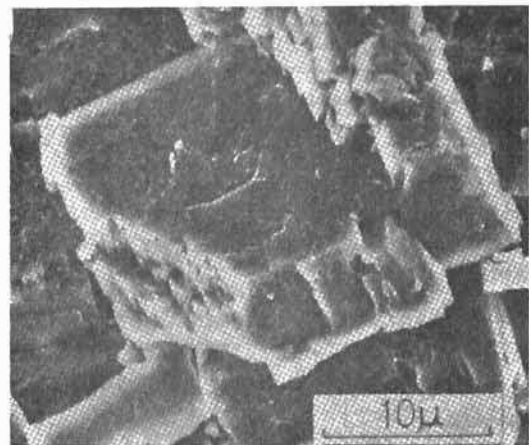
Fig. 6 Relation between the strength and the rate of carbonation



① 20°C ② 100% ③ 24 hr ④ 87%



① 50°C ② 100% ③ 24 hr ④ 90%



① 80°C ② 100% ③ 24 hr ④ 85%

- ① Carbonating temperature
- ② Concentration of CO₂ gas
- ③ Carbonating time
- ④ Rate of carbonation

Photo. 1 Section of specimen hardened on carbonation of slaked lime

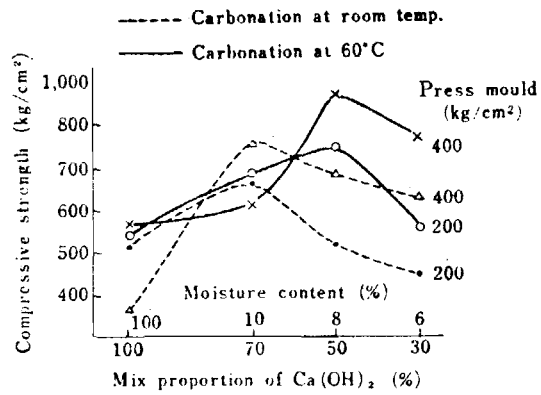


Fig. 7 Relation between the compressive strength and the mix proportion (lime stone aggregate)

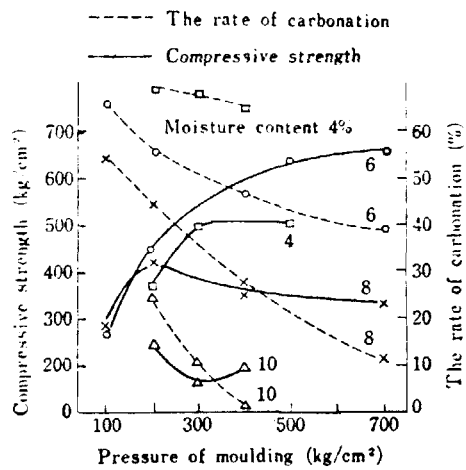


Fig. 8 Relation between the compressive strength and the pressure of moulding (lime stone aggregate)

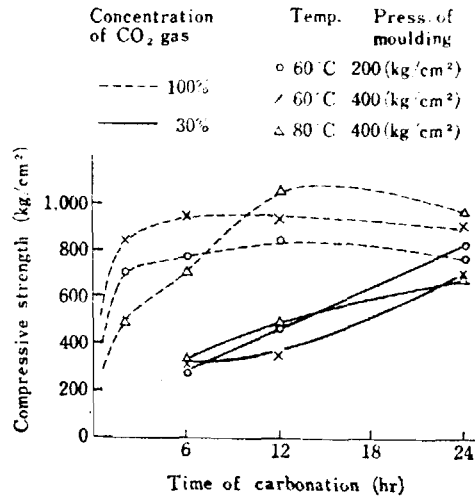


Fig. 9 Relation between the compressive strength and the time of carbonation (Ni-slag aggregate)

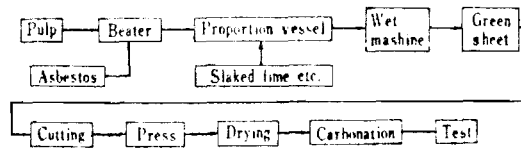


Fig. 10 Manufacturing process of fibre reinforced carbonate plate

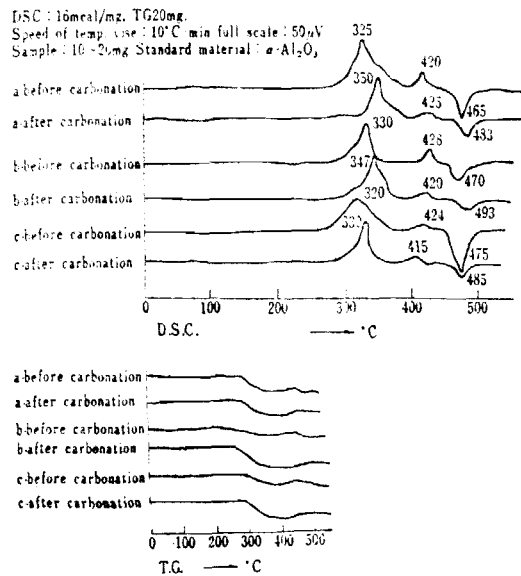


Fig. 11 Thermal analysis of carbonated specimen